International Journal of Electrical and
Electronics Engineering Research (IJEEER)
ISSN (P): 2250-155X; ISSN (E): 2278-943X
Vol. 8, Issue 3, Aug 2018, 19-28


# A REVIEW ON SINGLE PHASE TO THREE PHASE POWER CONVERTERS

**KAUSHAL W. KAKAD[1] & NITIN R. BHASME[2]**

[1]*PG Scholar, Department of Electrical Engineering, Government College of Engineering Aurangabad, India*

[2]*Faculty, Department of Electrical Engineering, Government College of Engineering Aurangabad, India*

***ABSTRACT***

***This paper describes the different configurations of single-phase to three-phase (SPTP) converter to supply three phase loads and power factor improvement. Various configurations for this are discussed in detail. The complete topologies are mainly divided a considering the number of components in the circuit. Considering this the comparison is made on the basis of voltage rating, current rating, and control complexity. The three-phase loads like induction motors and BLDC motors are considered for these converters. A parallel converter is also discussed in this paper considering power capability, efficiency, reliability, and redundancy.***

***KEYWORDS: AC-DC Converter, DC-AC Converter, Parallel Converter, Pulse Width Modulation & SPTP***

**Received**: Jun 14, 2018; **Accepted**: Jul 06, 2018; **Published**: Aug 02, 2018; **Paper Id**: IJEEERAUG20183

**Original Article**

## INTRODUCTION

Usually, it is common to have a single phase supply in rural, domestic and commercial sectors but the loads which are connected in three-phase configuration have more advantages in comparison with single-phase loads. This is true mostly in case of motors. This is because the three-phase motors have reduced size, weight and improved performance in terms of torque and power compared to single phase motors with the same rating.

In past years the SPTP conversion is done by using capacitors and reactors i.e. passive components because the costs of power semiconductor devices were high. Such a system leads to more disadvantages and limitations. But now-a-days with improvement in technologies, the cost of power semiconductor devices goes on decreasing. Hence size, weight, and losses of the converter reduce with the use of semiconductor devices.

As the technology of power semiconductor devices is improved they are used to drive the power processor more efficiently and economically. Also the use of power semiconductors in former converters and comparing their use in recent converters we can see the development of semiconductor devices. At the same time, there is a great improvement in the circuit topology of the SPTP converter.

According to literature survey, we can classify the SPTP converter as cascade type and unified type or as the converter with less number of switches and the converter with more number of switches. In cascade type converter the rectifier and inverter are separately controlled by PWM technique and dc link capacitor is connected in between them. The rectifier with PWM switching is used for the improvement of power factor and the inverter with PWM switching is used for speed control of a motor. Whereas in unified type converter the rectifier and inverter are combined together and the single PWM technique is used to control rectifier and inverter for power factor improvement and motor control.

Converters with a reduced number of components were the trend in past years, because of the high cost of power semiconductor devices. But as the technology got improved the cost of power semiconductor switches goes on reducing and the use of the converter with more number of components show up as the interesting choice. Also, it has advantages in terms of efficiency, reliability and distortion improvement [1]-[2].

In this paper, different topologies for the SPTP converter are depicted along with control technique. Comparison of the converter is shown with regard to the voltage rating, current rating, control complexity etc.

## 2. CONVENTIONAL TOPOLOGY

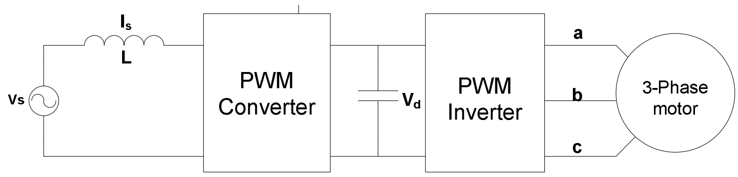



**Figure 1: Basic Structure of Conversion System**

Figure 1 shows the basic structure of the SPTP converter system. It consists of a single phase ac supply, smoothing inductor, converter with PWM switching used for power factor improvement, dc link capacitor and PWM inverter and three phase load. Figure 2 shows the conventional topology in which the rectifier and inverter contain the controlled switches such as IGBT, MOSFET or thyristor.

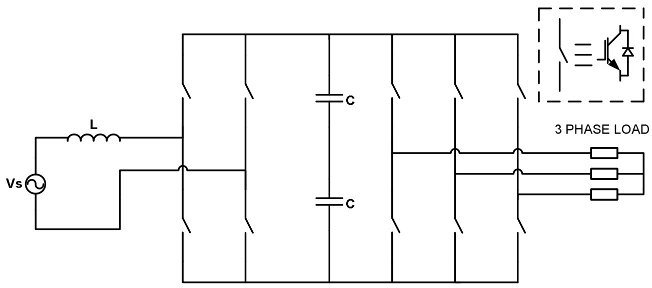



**Figure 2: Conventional Topology**

### 2.1. AC to DC Converter

AC to DC converter or commonly called as a the rectifier is a circuit to convert ac power to dc power. The most common ac to dc converter consists of diodes i.e. uncontrolled power semiconductor device. Hence power cannot be controlled in a diode rectifier. On other hand, when the controlled switches are used such as thyristors, MOSFET or IGBT the power flow can be controlled. But the fundamental downside of these converters is associated with harmonics and reactive power generation. The performance of the electrical system is severely affected by the presence of harmonics. Figure 3 shows the diode rectifier with a boost converter to boost the output voltage of the rectifier.

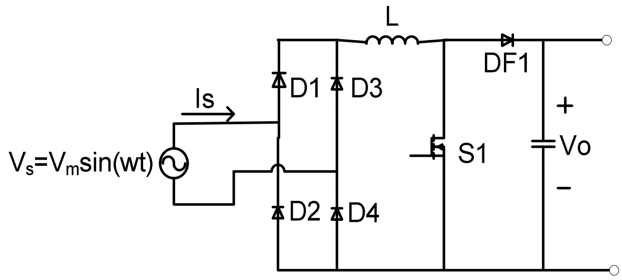



**Figure 3: Rectifier with Boost Converter**

Figure 4 shows the fully controlled bridge converter with dc link capacitor. The converter employs the four IGBT switches. The average output voltage of this converter is given as

$$V_0 = \frac{2V_m}{\pi} \cos \alpha \tag{1}$$

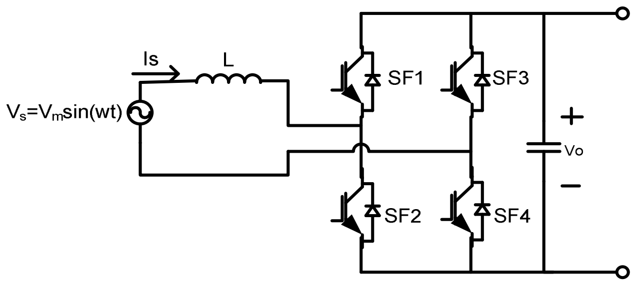



**Figure 4: Full Bridge Converter**

Figure 5 shows the semi-controlled bridge converter with a symmetrical configuration with the dc link capacitor. It employs two IGBT switches and two diodes.

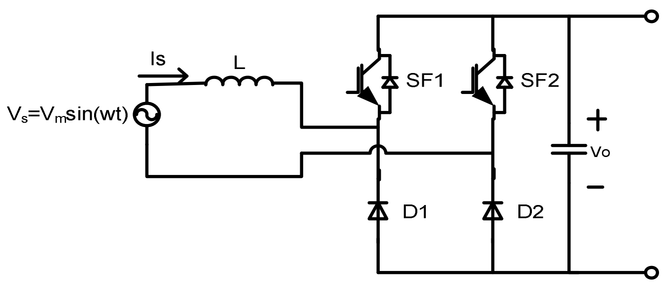



**Figure 5: Switch/Diode Type Converter**

In general, the PWM control technique for rectifier is used to synchronize the ac input voltage with ac input current to maintain the input power factor near to unity and to maintain the dc link voltage constant. The basic control scheme for the PWM bridge connected rectifier is shown in Figure 6. It consists of the voltage controller and current controller both are PI type controllers. The voltage controller is used to maintain the dc link voltage constant by comparing the output dc voltage of rectifier wit reference dc voltage. Similarly, the current controller is used to maintain the input power factor near to unity by comparing the input current with reference current [3].

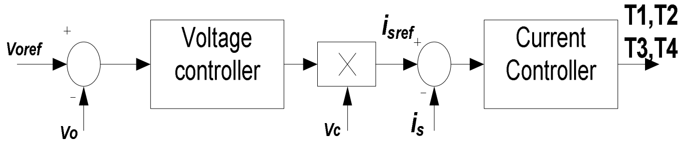



**Figure 6: Control Scheme for PWM Rectifier**

**2.2. DC to AC Converter**

DC to AC converter is called as the inverter which converts the dc power into ac power. The inverter converts the dc power to ac power at required voltage and frequency. The output voltage of the inverter could be fixed at fixed or variable frequency. The inverter usually employes the controlled power semiconductor devices such as BJTs, MOSFETs, IGBTs, GTOs or forced commutated thyristors.

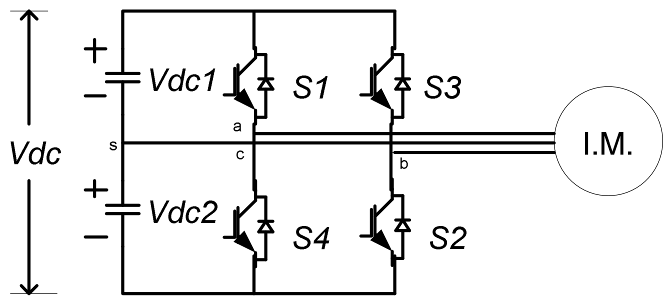



**Figure 7: Two Leg Inverter**

Above Figure 7 shows an inverter with two legs connected to the induction motor. In this inverter, the output is taken from the two legs and from the neutral point of dc link. Here the phase $a$ and phase $b$ of induction motor is connected to two legs of inverter and phase $c$ of induction motor is connected to the neutral point of the capacitor link. The inverter converts the input dc voltage obtained from the rectifier and gives it to the VVVF controlled induction motor. The line voltage $V_{ac}$ is obtained by controlling the switching of S1 and S4. Similarly the line voltage $V_{bc}$ is obtained by controlling the switching action of S3 and S2. For the induction motor drive, in balanced set, the three phase voltages of induction motor are given as,

$$V_{as}^{*} = V_m \cos(wt) \tag{2}$$

$$V_{bs}^{*} = V_m \cos(wt - \tfrac{2\pi}{3}) \tag{3}$$

$$V_{cs}^{*} = V_m \cos(wt + \tfrac{2\pi}{3}) \tag{4}$$

To control the voltage of the four switch inverter there are two methods. One is vector control by space vector modulation and other is scalar control. In scalar control, the switching time is calculated by using the phase voltage. The two line to line voltage of the induction motor is given as,

$$V_{ac}^{*} = V_{as}^{*} - V_{cs}^{*} = \sqrt{3}V_m \cos(wt - \tfrac{\pi}{6}) \tag{5}$$

$$V_{bc}^{*} = V_{bs}^{*} - V_{cs}^{*} = \sqrt{3}V_m \cos(wt - \tfrac{\pi}{2}) \tag{6}$$

The magnitude of line voltage is $\sqrt{3}$ times the phase voltage and it is phase displaced by $\frac{\pi}{3}$ radians with respect to

each other.

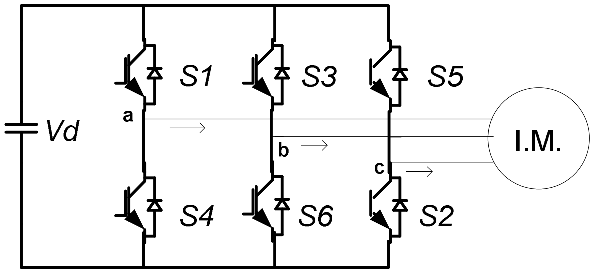
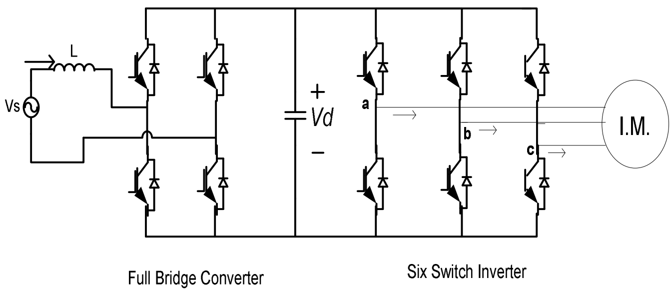



**Figure 8: Six Switch Inverter**

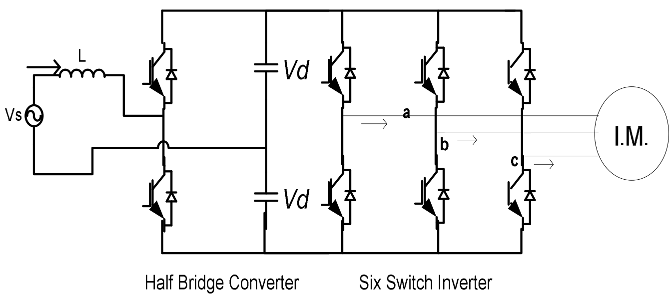
Above Figure 8 shows three-leg three-phase inverter. In two-leg inverter because of the natural voltage vector restriction, the 120° balanced current profile of three phase can be achieved by using PWM control technique having 60° phase shift. The major nuisance of using two-leg inverter is smaller voltage utilization and more harmonic components [4]. Because of this, it results in torque pulsations and harmonic copper losses.

## 3. CASCADE TYPE CONVERTER

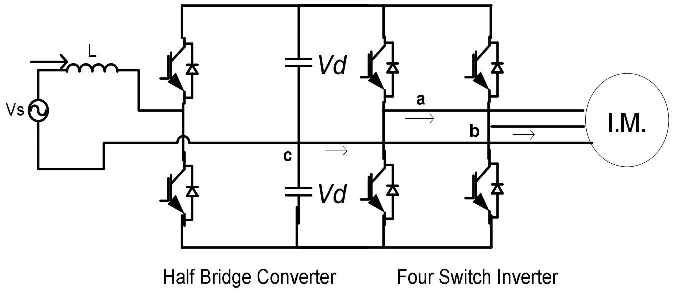
Based on the PWM rectifier which is represented in Figure 3 to Figure 5 and PWM inverter which is represented in Figure 7 and Figure 8 the entire cascade type converter configuration can be assembled as shown in Figure 9. The topology shown in figure 9 (C1) consists of full bridge converter and six switches inverter and in Figure 9 (C2) consists of half bridge converter and six switch inverter. The topology shown in Figure 9 (C3) has only six switches which are smallest compared to other configuration. It contains the half-bridge converter and four switch inverter.




*(C1)*




*(C2)*




*(C3)*

**Figure 9: Cascade Type AC-DC-AC Converter**

The system is shown in Figure 10 is cascade type SPTP converter. It consists of front end half bridge converter, dc link capacitor and two leg inverter which is used to drive three phase load. Front-end rectifier allows the bidirectional power flow between ac source and dc link. This configuration uses six IGBT switches. The four switch inverter converts the dc input voltage at dc link capacitor into balanced three phase ac voltage at desired voltage and frequency. Complex PWM control method is used to control the high-frequency devices such as IGBTs and MOSFETs etc.

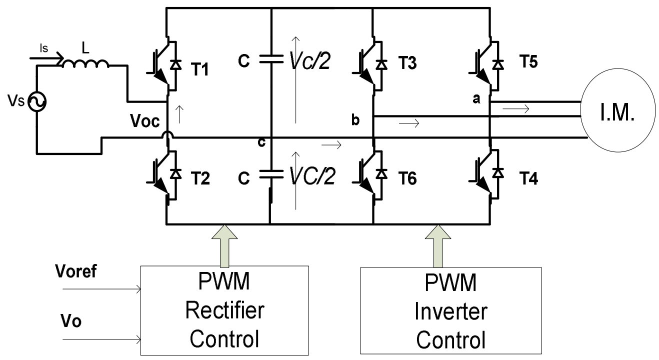



**Figure 10: SPTP Converter [4]**

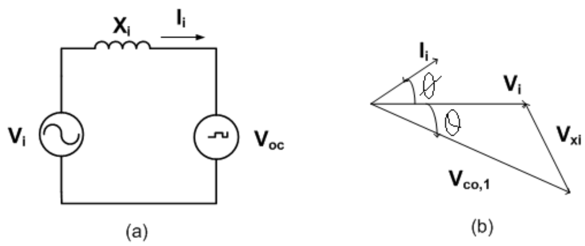



**Figure 11: (a) Front End Converter Equivalent Circuit Diagram**
**(b) Phasor Diagram**

The Figure 11(a) is the equivalent circuit of front side converter. Because of the PWM controlled switching of T1 and T2 the input side ac voltage is converted into dc voltage $V_{oc,1}$ which is nothing but the fundamental component of voltage at point '$o$' and 'c'. Complex PWM control technique used in rectifier eliminate the lower order harmonics. The phasor diagram is shown in Figure11 (b) gives the relation between input voltage $V_i\angle 0$ and$V_{oc,1}\angle\theta$. The voltage $V_{oc,1}$ lags the voltage $V_i\angle 0$ by angle$\theta$. The input current given in Figure 11(a) is expressed as,

$$I_i\angle\phi = \frac{V_i\angle 0 - V_{oc,1}\angle\theta}{jX_i} \tag{7}$$

The active power $P_i$ which flows from the ac source to the dc-link capacitor can be given by,

$$P_i = \frac{V_i V_{oc,1}}{X_i} \sin\theta \tag{8}$$

Because of the asymmetrical voltage such as two stepped and three stepped present in the three-phase output of inverter it will not eliminate all the tripplen harmonics but only eliminate the finite number of non-tripplen harmonics by PWM control technique [4].

## 4. CONVERTER USING TWO PARALLEL RECTIFIER

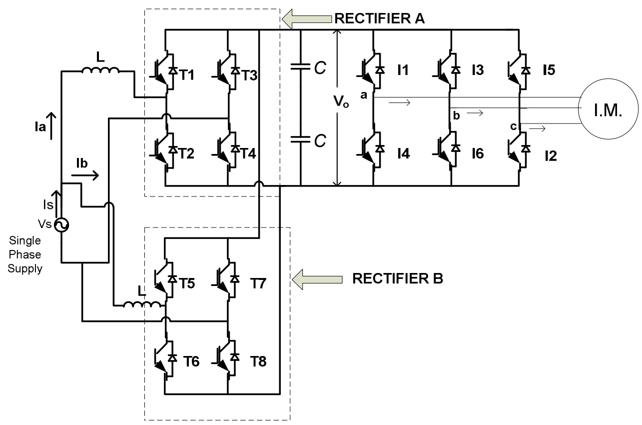



**Figure 12: Parallel Rectifier Connected SPTP Converter (C4)**

The system depicted in Figure 12 is consist of single- phase supply connected to front end rectifier connected in parallel, input inductors, dc link capacitor bank and an SPWM control inverter. The two rectifiers connected in parallel in which the upper rectifier consist of four IGBT switches $T_1$, $T_2$, $T_3$, $T_4$ similarly the lower rectifier consist of four IGBT switches $T_5$, $T_6$, $T_7$, $T_8$. The three-phase three-leg inverter consist of six IGBT switches namely $I_1$, $I_2$, $I_3$, $I_4$, $I_5$, $I_6$. In between the rectifier and inverter the dc link capacitor bank is connected which is used to remove the ripple content of rectifier output. The output of three-phase inverter is given to three-phase asynchronous motor. Considering all the supply inductor equal the equations of the parallel connected configuration can be given as

$$i_s = i_a + i_b \tag{9}$$

$$V_o = V_a + V_b \tag{10}$$

$$V_a = V_s - 2(r + pl_a)i_a \tag{11}$$

$$V_b = V_s - 2(r + pl_b)i_b \tag{12}$$

Where, $i_s$ is supply current, $V_o$ output voltage, $V_a$ rectifier A voltage, $V_b$rectifier B voltage, $p = \frac{d}{dt}$ and r&l represents the resistance and inductance of the inductor. The THD is calculated to find out the harmonics distortions in voltage of the converter. It is calculated by considering weighted THD as

$$Weighted\ THD_p = \frac{100}{a1}\sqrt{\sum_{i=2}^{p}\left(\frac{a_i}{i}\right)^2} \tag{13}$$

Where $a_1$ is the fundamental voltage amplitude, $a_i$ is the $i_{th}$ harmonic amplitude and $p$ is the number of harmonics [5].

## 5. COMPARISION

This section gives the general comparison of the converter topologies presented here. The comparison includes the voltage rating, current rating, control complexity and input current shaping.

**Table 1: Comparison of Different Topologies [1]**

| | Topology | | |
|---|---|---|---|
| | Half Bridge Converter-SIX Switch Inverter(C2) | Half Bridge Converter- Four Switch Inverter (C3) | Parallel Rectifier Connected SPTP Converter (C4) |
| Current rating (pu) | 4.0 | 3.0 | 1.5 |
| Voltage Rating (pu) | 2.0 | $2\sqrt{3}$ | $\sqrt{3}$ |
| Control complexity | High | Moderate | Higher |
| Input current shaping | Yes | yes | yes |

## 6. APPLICATION

For economy and efficiency, three-phase motors are used in large commercial and industrial areas where three phase supply is readily available. But for rural, residential and light commercial areas where available power supply available may be single phase and three phase supply is required by the customer from utility but it is uneconomical for the utility to do so. In that case to drive the three-phase loads SPTP converter is useful. The main advantage of this system is power stress on switches is minimized but the limitation is that line output voltage is limited because of the amplitude of supply voltage. Another application of these converters is of use as an active filter to minimize the power stress on switches. [6]. Also instead of using LC filter, an active filter is used with these converters to improve the performance of linear and non-linear loads such as power quality and power factor [7]. These converters are used in locomotives to drive three phase ac motors. In addition, also used to drive the pumps and auxiliary fans in traction system[8].

## 7. CONCLUSIONS

The paper shows the SPTP converter with less number of components and with more number of components and these systems are compared with each other. From the comparison point of view, the converter having parallel rectifier at the front end have less a current rating and voltage rating, but the control complexity is higher. Also compared to other topologies, the system with two rectifiers reduces the THD of input current with same the switching frequency.

***REFERENCES***


1. *C. B. Jacobina, E. C. Santos* and *N. Rocha,"Single phase to three phase power converters: State of the art," IEEE transactions on power electronics,* vol *27,* no. *5,* may *2012*.
2. *B. Fahimi* and *B. K. Lee,"Overview of reduced part converter topologies for AC motor drives,"* in *Proc. IEEE PESC* pp. *2019-2024, 2001*.
3. *J. R. Espinoza, P. Lezana, J. R. Roclriguez J. Pontt* and *J. W Dixon,"Regenerative rectifiers: A State of the art," IEEE transactions on industrial electronics,* vol. *52,* no. *1,* feb *2005*.
4. *P. N. Enjeti, A. Rahman,"A new single phase to three phase converter with active input current shaping for lo w cost ac motor drives," IEEE transactions on industary applications,* vol, *29,* no. *4,* july/august *1993*.
5. *C. B. Jacobina, E. C. das Santos* and *E. L. Lopes Fabricio,"Single phase to three phase drive system using two parallel single phase rectfiers,"IEEE transactions on power electronics,* vol. *25,* no. *5,* may *2015*.

6. *Anssari, O. M. H.,* & *Kumar, P. S. Three Phase Single Stage Three-Thirteen Level Ac-Dc Converter*.

7. *H. Fujita,"A single phase active filter using an H- bridge PWM converter with sampling frequency quadruple of the switching frequency," IEEE transactions on power electronics*, vol. *24*, no. *4* pp. *934-941*, april *2009*.

8. *R. Q. Machado, S. Buso, "A line interactive single phase to three phase converter system," IEEE transactions on power electronics*, vol. *21*, no. *6*, pp. *1628–1636,* May *2006*.

9. *P. Enjeti* and *R. Jakkli*, "*Economic single phase to three phase converter topologies for fixed frequency output,*" *in Proc. 6th Applied power electronics conference and exposition*, pp. *88–94,* Mar. *1991*.